§26. Kinetics of Hydrogen Isotopes at Surfaces and Bulks of Plasma Facing Materials Based on Group 5 Metals

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Group 5 metals including V are candidate materials for superpermeable membranes used to pump the fuel particles in edge plasma. In addition, V alloys have attractive mechanical and nuclear properties as structural materials of fusion blankets. From these viewpoints, the interactions of hydrogen plasma and gas with pure V and V alloy were investigated by several different experimental techniques.

The regime of *superpermation* is achieved by the strong suppression of reemission of incident hydrogen particles by non-metallic surface impurities such as oxygen and sulfur. In other words, removal of surface impurities by sputtering leads to the reduction in permeability. Therefore, the durability of V superpermeable membrane under sputtering was examined by the permeation device described elsewhere[1]. Namely, the plasma-driven permeation rate of hydrogen was measured for a membrane of pure V (0.1 mm in thickness) at the bias voltage of 0 - 260 V and the incident ion flux of 0.6 - 1.2 × 10^{19} $m^{-2}s^{-1}$. The temperature of the membrane varied with bias voltage owing to the change in energy deposition from plasma in the range from 430 to 560 ºC. A typical result is shown in Fig. 1. It should be emphasized that no significant reduction in the permeation rate was observed even in the range of bias voltage above 100 V where the degradation of Nb membrane took place[2]. This result indicates that non-metallic impurities removed from the surface by sputtering were compensated instantly by those segregated from the bulk in the temperature range examined.

Surface analysis by means of X-ray photoelectron spectroscopy (XPS) was carried out for a pure V specimen heat-treated in an ultra-high vacuum. It was shown that oxygen was the major surface impurity below 800 ºC, while sulfur became dominant at 1000 ºC. It appears that the sustained superpermeation under sputtering was due to the continuous surface segregation of oxygen from the bulk. Surface analysis after hydrogen ion bombardment, however, is necessary to derive a conclusion.

Interaction of hydrogen gas with the surfaces of V and V-4Cr-4Ti alloy (NIFS-Heat-2) was examined by absorption experiments. The details of experimental procedure are described elsewhere[3]. In the case of V-4Cr-4Ti alloy, the sticking coefficients of H_2 and D_2 were markedly reduced by heat treatments at 700 ºC for 1 h, whereas no significant change was observed for pure V at this temperature. Surface analysis by XPS showed that Ti in V-4Cr-4Ti alloy was segregated to the surface above 700 ºC. In addition, the surface coverage of oxygen increased by the surface segregation of Ti through preferential interaction between oxygen and Ti. The reduction in the sticking coefficients was ascribed to this increase in oxygen coverage. It was concluded that the interaction between V alloy and gaseous hydrogen is sensitively dependent on the heat treatment condition through the redistribution of Ti.

Trapping effects for hydrogen isotopes (tritium) absorbed in V-4Cr-4Ti alloy were shown by diffusion experiments below 250 ºC. Observation of concentration distribution of tritium by imaging plate technique indicated that the distribution of trapping sites is also influenced by the fabrication process including heat treatment conditions.

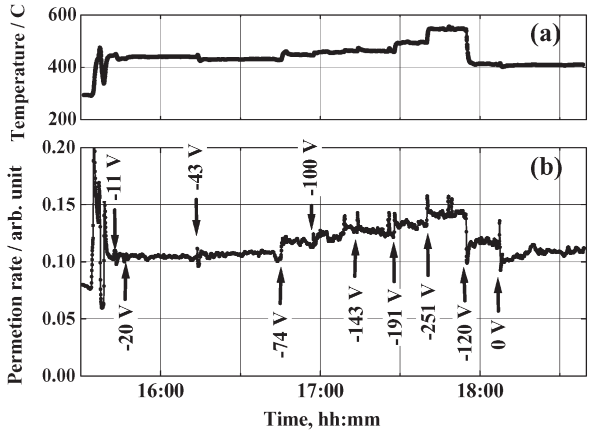

Fig. 1 Influence of bias voltage on membrane temperature (a) and plasma-driven permeation rate of hydrogen (b).

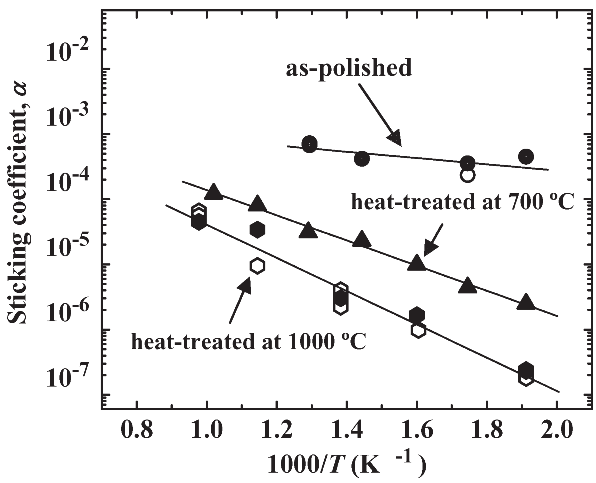

Fig. 2 Sticking coefficients of H_2 (filled symbols) and D_2 (open symbols) on surface of V-4Cr-4Ti alloy under different heat treatment conditions.

References

1) Hatano, Y. et al., Annual Report of Hydrogen Isotope Research Center, Toyama Univ. 21(2001)13.
2) Nakamura, Y. et al., J. Appl. Phys., 89(2001)760.
3) Hatano, Y. et al., Mater. Trans. 46(2005)511.